Remote Sensing

Introduction

All of us perceive the environment with our senses. Some senses require us to come in contact with what we are sensing - we touch and taste. Some senses allow us to perceive objects at a distance - we see and hear. In this second case, we are sensing objects or phenomena that are remote from our eyes or ears - we are doing remote sensing. By using the microscope, telescope, camera and film, microphone, amplifier, and speaker, and video camera and television we expand our remote sensing capabilities. These technologies allow us to see farther, to observe finer details, and to perceive fainter signals than our unaided senses.

Our remote sensing capabilities come in a mobile package complete with an energy source and data processing and storage facilities - we turn our heads to gaze in different directions, move to get a better view or to hear more clearly, make decisions based on what we sense, and remember sights and sounds. To see more of the environment around us, we can climb a ladder, a tree, or a hill and gain a wider view. Until the advent of hot-air balloons in the last century, these were the only ways for humans to get a bird's eye view of the Earth. With the invention of cameras in the mid-1800s, people began to make aerial photographs from balloons. One of the first balloon photographs was of Boston, Massachusetts, USA, taken in 1860 from 1200 feet above the city. A particularly intriguing photograph was taken of the 1906 San Francisco earthquake and fire using an array of 17 kites moored to a boat anchored in San Francisco Bay!

Prior to 1960, the most widely used remote sensing systems were based on the camera, although infrared film and radar had been developed and used during World War II. Space-based remote sensing began in 1960 with the launch of the first Television Infrared Observation Satellite (TIROS I). The TIROS series of satellites initially focused on providing images of clouds and were the predecessors of the present National Oceanic and Atmospheric Administration (NOAA) polar-orbiting weather satellites. The first remote sensing satellite focused on the land surface was the Earth Resources Technology Satellite (ERTS I) launched by the National Aeronautics and Space Administration (NASA) in July 1972. Later, this satellite was renamed Landsat I, and became the first of a series of Landsat satellites designed to image and map land surface features. Today, there are dozens of environmental satellites launched and operated by various countries and multinational organizations.

Initially, the costs associated with these technologies restricted their use to large government and private organizations. More recently, the power of desktop computing and the proliferation of satellites from many countries have opened this frontier to people everywhere. Now, small colleges and businesses, elementary and secondary schools, land planners, environmental groups, and even individuals make use of satellite remote sensing technology.

Various images derived by remote sensing techniques appear throughout this guide. Some look like photographs – indeed some are photographs. The *Blue Marble*, perhaps the most famous image of the Earth from space, is a photograph taken by Apollo 17 astronauts on their journey to the Moon in December 1972. See

Figure IMP-I-1. Other images may look to you like abstract paintings. Today, most remote sensing images are not photographs; they are digital images sensed on solid-state detectors and converted to numbers which are transmitted, stored, and displayed by computers. The remote sensing instruments on Landsat produce this type of digital image. Wherever possible, each GLOBE school is provided with an image of its GLOBE Study Site taken from a Landsat satellite by an instrument named Thematic Mapper (TM).

Figure IMP-I-1: The Blue Marble–Photograph taken from Apollo 17, December 1972

Source: NASA

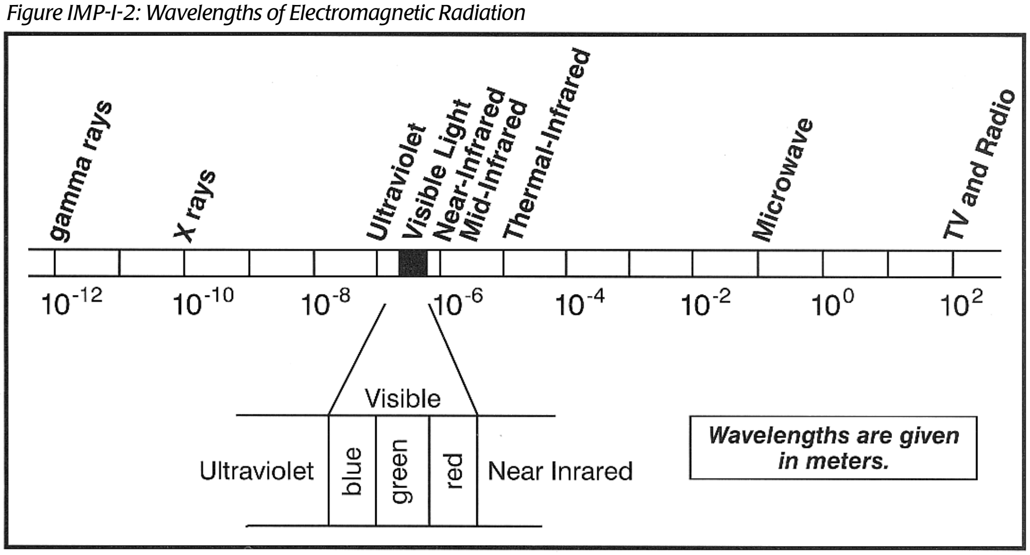
What Properties of a GLOBE Study Site Does the Thematic Mapper Measure?

The TM's sensors record visible and infrared (IR) sunlight that is reflected from the Earth outward into space. Thematic Mapper also includes sensors that detect IR radiation or light that is emitted by the Earth, but this part of TM's capabilities are not used in GLOBE.

Visible light is *electromagnetic radiation* or *light waves* that can be detected by our principle remote sensing capability, the human eye. It is said that the human eye provides us with about 90% of the information we receive about our environment. Visible light, however, is only a small part of a very large continuum of light waves. See Figure IMP-I-2. This radiation forms a continuous spectrum in which the differing waves are characterized by their wavelengths. Wavelengths are commonly measured in one of two units, the micron (micrometer, µm), where 1 µm = 1 x 10^{-6} m (0.000001 m), or the nanometer (nm) where 1 nm = 1 x 10^{-9} m (0.000000001 m). The shortest wavelengths are associated with gamma rays, whose wavelengths are about 10^{-6} µm, while at the long end of the scale, radio and TV waves have wavelengths of 10^{+8} µm (=100 meters). Visible light lies close to the middle of this spectrum with violet light being the shortest wavelength, and red light the longest. Measured in nanometers, the wavelengths of visible light range from 400 nm for violet to 700 nm for red.

On either side of the wavelength *band* of visible radiation are other wavelengths of value in remote sensing. At wavelengths just longer than visible light are the three bands of infrared light–near, middle, and thermal. The image of the GLOBE

Figure IMP-I-2: Wavelengths of Electromagnetic Radiation

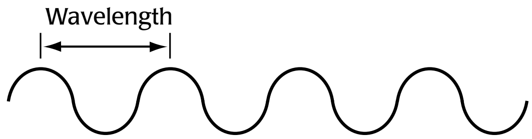


Source: GLOBE

Wavelengths of visible light:
Blue visible light: 4.5 x 10^{-7} meters
Green visible light: 5.5 x 10^{-7} meters
Red visible light: 6.5 x 10^{-7} meters

The labeled wavelengths in the electromagnetic spectrum diagram are the center of a range (or band) of wavelengths for that type of wave. The types of waves are not clearly separated. Think about a rainbow with its bands of red, orange, yellow, green, blue, and violet light. The colors of the visible light waves blend into one another. For our purposes, we will use the labeled wavelength (center of the range) in the diagram.

Figure IMP-I-3: Wavelength



Wavelength is defined as the distance between two successive crests (or troughs) in a wave, as shown above.

When you think of wavelengths of radiation you can think of ocean waves. Wavelengths are measured from the crest of one wave to the crest of the next. Think of waves you have seen on lakes or the ocean. How far apart were the crests of those waves?

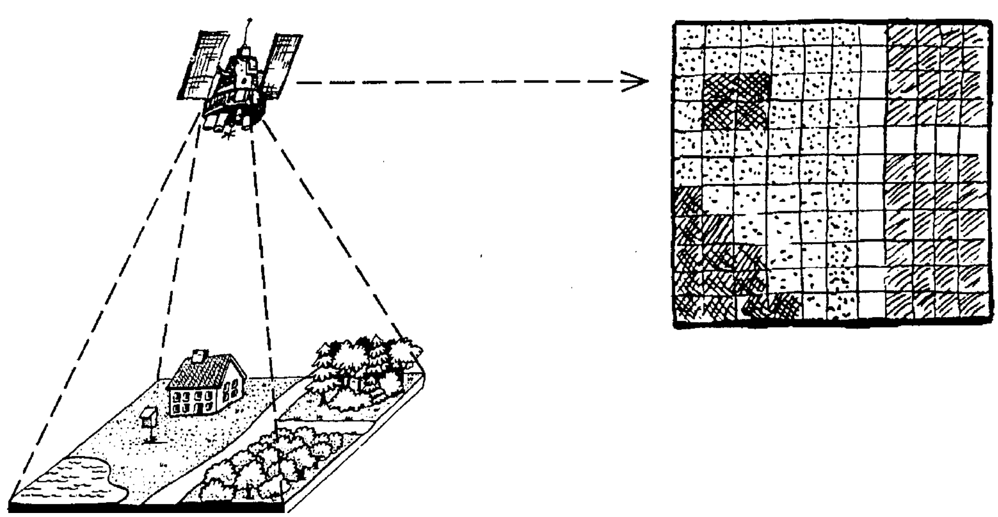
Study Site is provided in TM's three visible bands (blue, green, and red), one near IR band, and one of its two middle IR bands. These visible and infrared data are used to assess extent and the health of crops, forests, and other forms of vegetative cover.

In each band, the TM measures the intensity of light reaching its detector from a specific place on the Earth and records this intensity as a number ranging from 0 to 255. In the binary or base 2 system of counting, it takes eight digits or places to count up to 255 and since each binary digit is referred to as a bit, TM is said to provide eight-bit data. The detectors and optics of TM were constructed so that from the 705 km orbital altitude of Landsat, the specific place reflecting light into an individual detector is 30 m by 30 m on the Earth's surface. Because of this, TM is described as having a spatial resolution of 30 m. Objects on the surface which are smaller than 30 m will be averaged together with their surroundings in the intensities measured and cannot be directly seen in a TM image.

Satellite Images

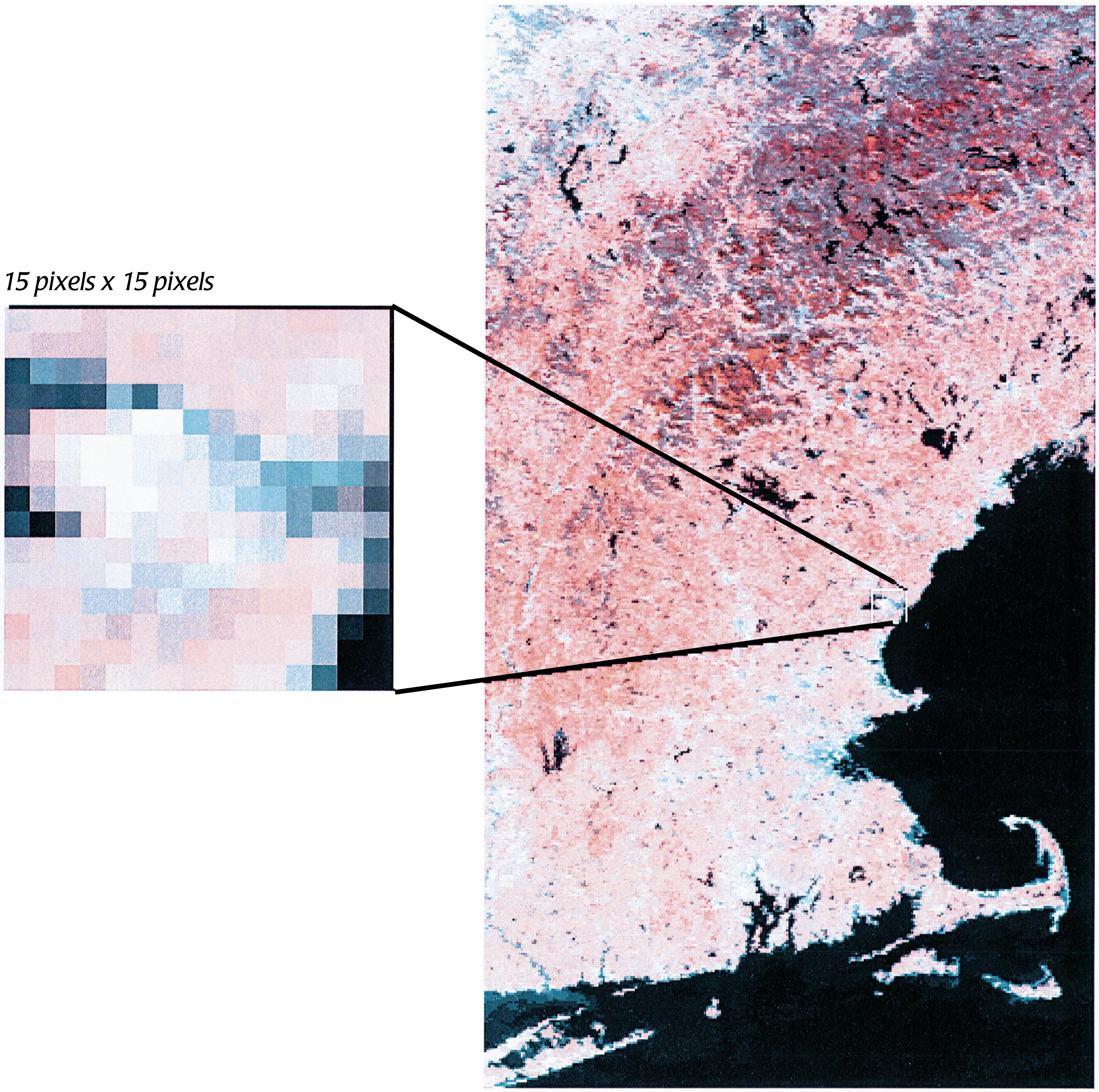
A picture of a large area of the Earth's surface can be produced by assembling the intensities measured for many adjacent 30 m by 30 m areas. If you look at a computer or television screen or at a pictures in a newspaper or comic book through a magnifying glass you will see small individual dots of color. Our eyes normally see this array of dots as a continuous image. Each of the dots is a picture element or pixel. To produce a digital image using TM data, a computer uses each intensity value to determine the brightness of one pixel on its screen. When fully displayed, each pixel in an image on the computer screen corresponds to a particular location on the Earth. This concept can be observed in the *blockiness* that is apparent when one blows up or zooms in to view a digital image more closely. See Figure IMP-I-5.

Figure IMP-I-4: Gridded Landscape



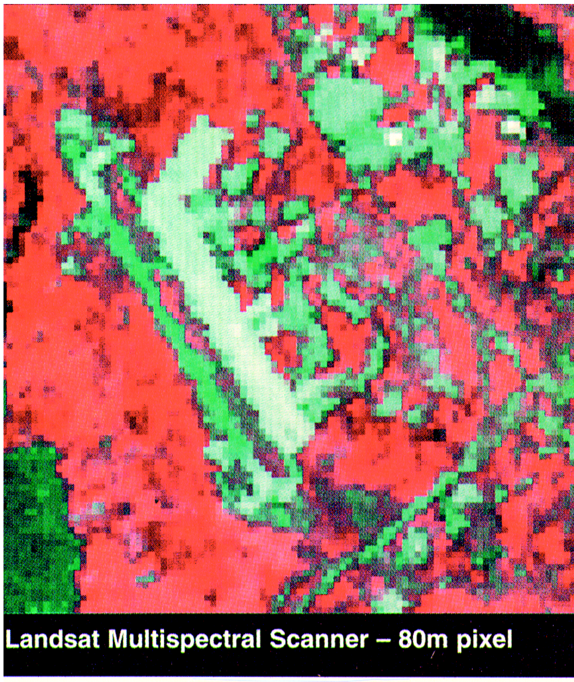
This represents how a satellite views the earth's land cover as a group of equal size units placed on a landscape. Each unit is called a pixel. Source: Jan Smolik 1996 TEREZA Association for Environmental Education, Czech Republic

Figure IMP-I-5: AVHRR Image



Source: NASA

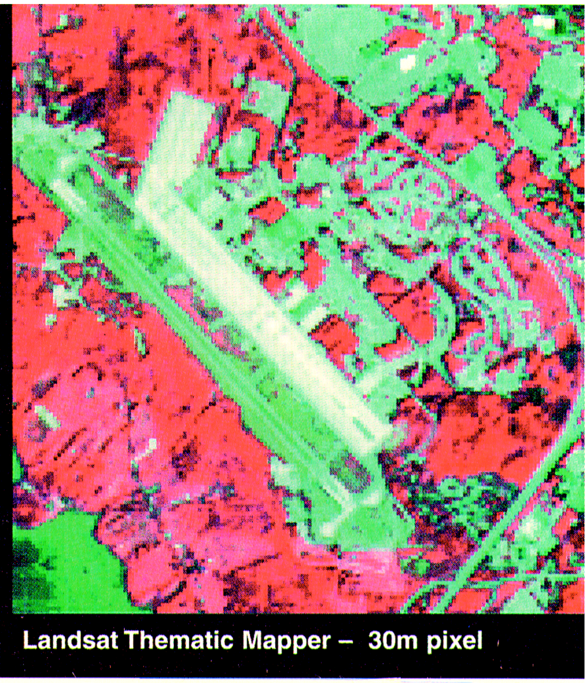
A false color infrared image of New England from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard a NOAA polar orbiting satellite. Each pixel in this scene is approximately 1.1 km on a side. The enlarged section shows a 15 pixel by 15 pixel area which is roughly the size as a GLOBE Study Site and which includes roughly the same section of Portsmouth, N.H., as Figures IMP-I-6 through IMP-I-9. The brightest pixels in this enlarged section represent the runway and apron area used to park aircraft and service vehicles



Landsat Multispectral Scanner – 80m pixel

Figure IMP-I-6

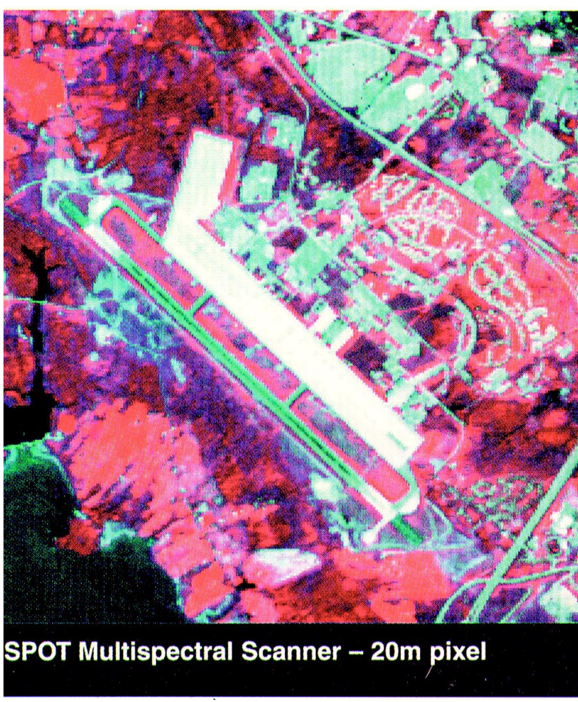
This Landsat Thematic Mapper Image shows the same area as Figure IMP-I-4 with the 80 m resolution Multispectral Scanner flown aboard the first five Landsat satellites. In this view, the parking area is seen, but few other ground details are visible.



Landsat Thematic Mapper – 30m pixel

Figure IMP-I-7

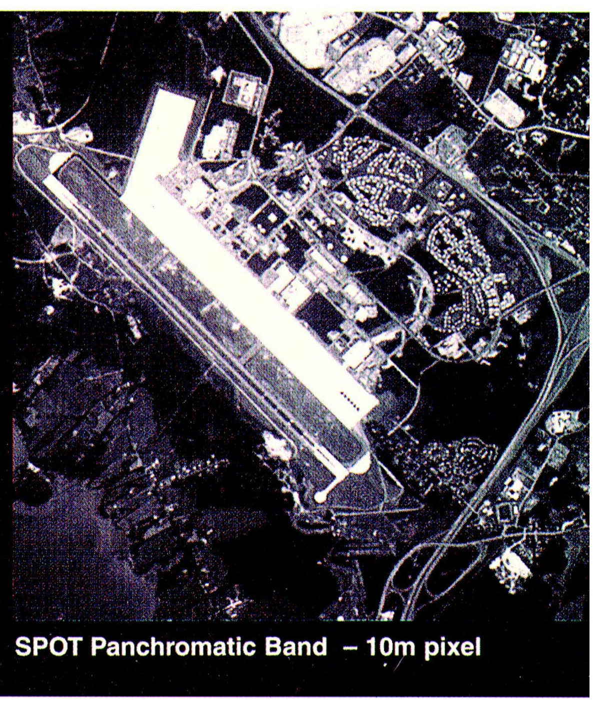
The Landsat Thematic Mapper Image of the same area as Figures IMP-I-4 and IMP-I-5 with 30 m. In this view, main roads are visible. These data have a high enough resolution to see features as small as a house. They are preferred for many types of ecological and environmental studies as they have both high spatial and spectral resolution.



SPOT Multispectral Scanner – 20m pixel

Figure IMP-I-8

Pease, N.H. at the 20 m resolution of the French SPOT satellite's Multispectral Scanner. In this view, secondary roads and structures can be seen.



SPOT Panchromatic Band – 10m pixel

Figure IMP-I-9

Pease, N.H. at the 10 m resolution of the French SPOT satellite's Panchromatic imager.

Source: Used with permission of the Earth Day Forest Watch Program, University of New Hampshire, Dr. Barry Rock and Mr. Gary Lauten

Figure IMP-I-10: Land-water area of Canberra, Australia, viewed in the near-infrared band only. Note that the water appears black. Source: EROS Data Center

Figures IMP-I-6 through IMP-I-9 show several satellite views of approximately the same area, the Pease International Tradeport in Portsmouth, New Hampshire, USA at several different spatial resolutions to demonstrate the effect of pixel size on image quality.

As the size of a pixel decreases, the amount of information needed to make an image of the same size area on the ground increases. Limitations in computer storage can make it impractical to use high resolution data when studying very large areas. The purpose of an investigation must therefore be considered when deciding which satellite or other remote sensor(s) to use. For GLOBE the 30 m by 30 m pixel size of Landsat is most appropriate. With this pixel size, the 15 km by 15 km area of a GLOBE Study Site can be covered by an image of 512 pixels by 512 pixels. Storing each TM band of such an image requires 256k bytes of memory and five bands fit nicely on a single floppy disk.

Our eyes can see in color as well as in black and white. If only one band of TM data is used to construct an image, it can be fully represented using 256 different shades of gray which our eye perceives as amounts of brightness. See Figures IMP-I-9 and IMP-I-10. The full range of colors we see can be produced by combining light of three different colors, for instance red, green, and blue on a computer screen or yellow, red, and blue when mixing paints. See Figure IMP-I-11. On the computer screen or on a printed image, each pixel is produced by a combination of red, green, and blue. This allows us to view images of three different bands of TM data simultaneously. If we let the intensity of the red band of TM determine the amount of red in the corresponding pixel, the green band determine the amount of green, and the blue band the amount of blue, the resulting image will closely resemble what our eye would see looking down at the Earth's surface and is referred to as a visible image. Alternatively, the red portion of each pixel can be determined by the intensity of near IR light detected by TM, the green determined by the intensity of red light, and the blue determined by the intensity of green light to produce a *false color infrared* image roughly corresponding to IR sensitive camera film. Figure IMP-I-12 shows such an image of a land and water area in Prague, the Czech Republic. Other band combinations are also possible, but in each case we are limited by the capability of our eyes to seeing at most three bands of TM in a single image.

Spectral Patterns

Let's consider what the different colors mean. When white sunlight (comprised of all colors) is incident on an object, some of the colors are absorbed and others are reflected. For example, an object that appears red is reflecting red light while absorbing all other colors. See Figure IMP-I-13. If all incident light is reflected, the object appears white, whereas if all the light is absorbed, the object appears black.

The key to interpreting multispectral data is understanding the reflectance properties of different surfaces or objects viewed by the sensor. The tendency of an object to reflect or absorb solar radiation at different wavelengths gives rise to its *spectral pattern*. See Figure IMP-I-11. Just as a person can be identified by his or her picture, spectral and spatial patterns can be combined to identify a remotely sensed object or surface feature. We can predict the spectral patterns of objects within the range of visible light, since this is the spectral region that we see. For example, we would predict the ocean to have a higher reflectance in blue spectral bands and the ocean appears blue in a visible image because most of the light entering the ocean is absorbed, while only the blue light is reflected. We would expect vegetation to have high reflectance in green because leaves are green, and so forth.

TM is not limited to detecting only in the visible range. Scientists have learned to interpret reflectance patterns outside the visible spectral region, and, in many instances, it is this invisible information that accounts for the power of multispectral imagery. Near infrared (NIR) radiation is almost completely absorbed by water, whereas land and particularly vegetation have high reflectance in the NIR region. Thus, the NIR bands are useful in differentiating land and water. In addition, the NIR bands are useful in locating and identifying different species of vegetation, and in determining whether or not particular plants healthy or diseased. Middle infrared (MIR) bands are sensitive to moisture content and, therefore, they are also useful in vegetation studies.

Satellite Orbits and Instruments and the Timing and Frequency of Observation

Another important aspect of satellite remote sensing is the frequency of coverage, that is, how often the satellite passes over a location on the Earth's surface. This is determined by the orbit in which the satellite is placed and the width of the area it images on the Earth's surface. The higher

Figure IMP-I-11: Reflectance of Some Targets

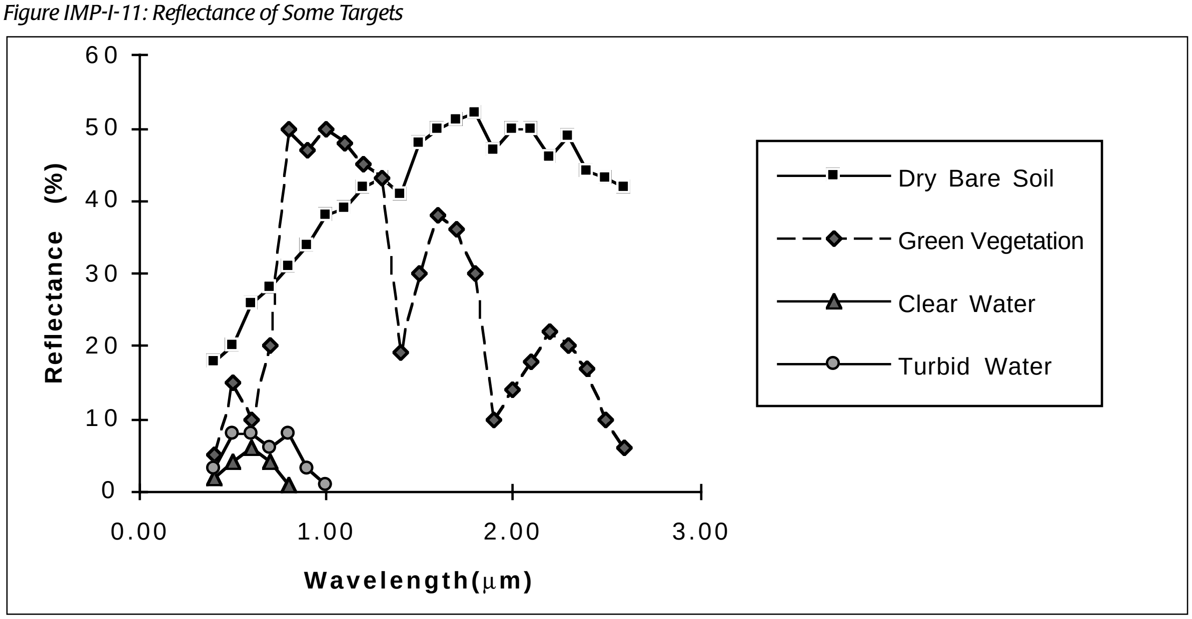
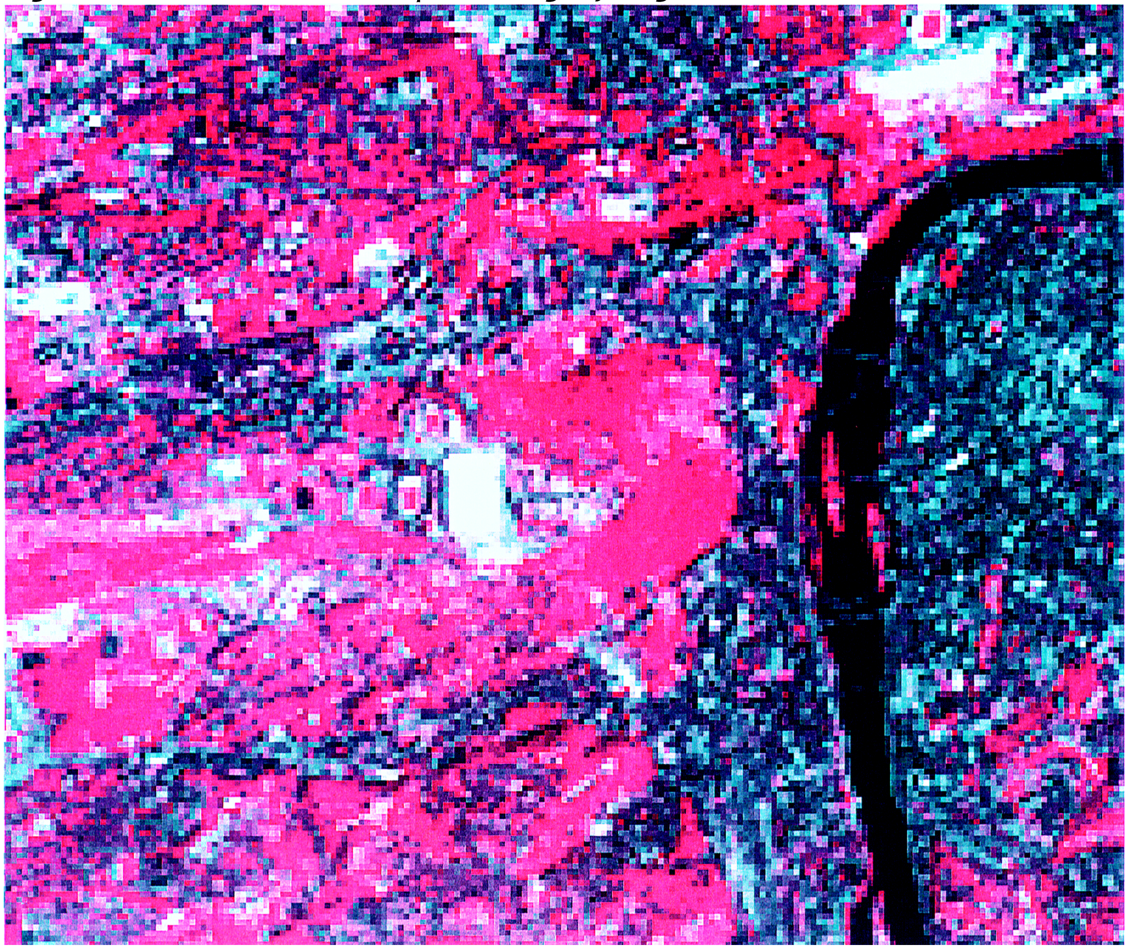
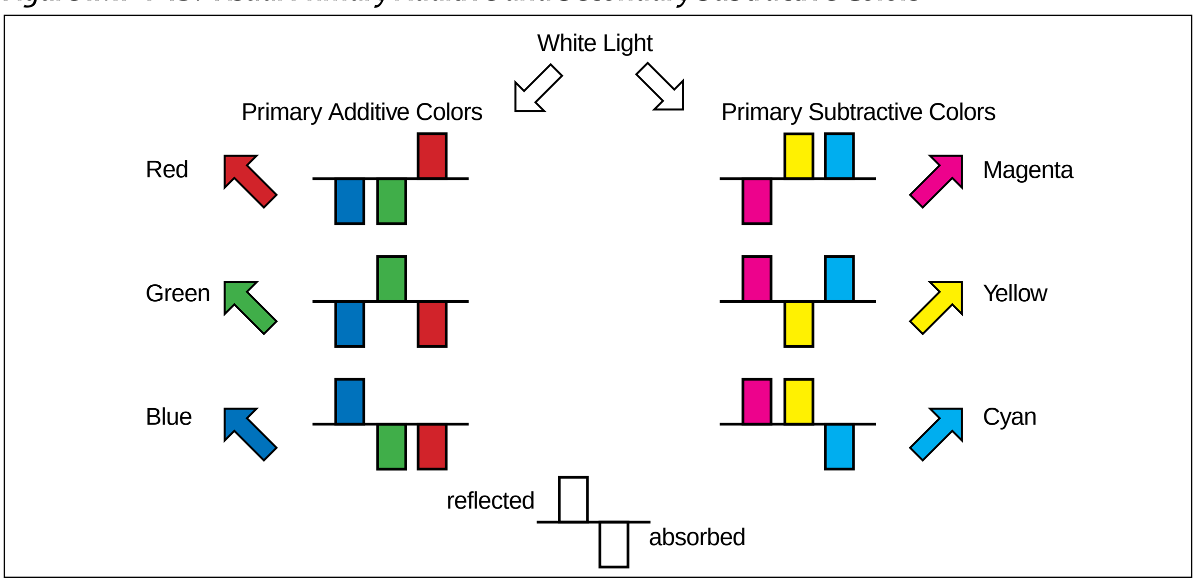


Figure IMP-I-12: False Color Composite Image of Prague



A false color composite image of part of the city of Prague, in the Czech Republic. Water appears black, developed areas of white to gray, and vegetated areas red. Source: EROS Data Center

Figure IMP-I-13: Visual Primary Additive and Secondary Subtractive Colors



Additive Primary and Secondary colors are produced when objects absorb and reflect different combinations of the colors found in white light. Source: GLOBE

the orbital altitude, the longer the time required for the satellite to orbit the Earth. As a general rule, the smaller the size of the pixels in a remote sensing instrument, the narrower its field of view. The orbit of Landsat and the width of the TM image area were chosen to provide coverage of every place on the Earth's surface at least once every 16 days (except for small regions surrounding the poles which are never imaged).

The orbit was also chosen so that Landsat always passes overhead at the same local time each day. At the equator this time is about 9:45 am. Such orbits are called sun-synchronous. Sun angles, shadows and other such effects visible in TM images remain similar or vary slowly in predictable ways.

As the Earth progresses through the seasons, the reflectivity of the land surface changes principally due to changes in vegetation and the distribution of snow cover and sea ice. The changes in vegetation occur slowly as a result of seasonal changes in deciduous plants and the amount of moisture available to plants resulting from seasonal precipitation patterns.

Implications for the Planet

Although the science of remote sensing has evolved steadily since the first Earth observing satellites, the challenges of interpreting remote sensing data remain large. Satellite images are far more complex than simple photographs. An image based on multispectral data involves measurements of reflected or emitted radiation in several bands. Because human experience is limited to visible sunlight, we have no intuitive knowledge of how features on Earth respond to other forms of electromagnetic radiation. We must rely on experiments, often involving ground-based measurements and airborne instruments, to learn how various features will reflect or emit radiation in different regions of the spectrum.

With satellite images, the possibility of monitoring and analyzing critical environments anywhere in the world is greatly expanded. Ecologists can study natural and human-induced changes in land use patterns and the global distribution of major *biomes*. Atmospheric chemists can relate these changes to increases in greenhouse gases, and oceanographers can study physical, chemical, and biological processes at the atmosphere-ocean interface (i.e. the sea surface). Students, too, can gain valuable insights into the nature of their own environment and share these with students from around the world.

Winston Churchill is credited with having said that the farther away from something one gets, the farther into the future one sees. With remote sensing images, students worldwide can step back into space, and view their home as a whole - a self-contained life-support system powered by the sun. How fast can it, has it, and will it adapt to changes of various sizes, and what are the consequence for our communities? By viewing the Earth with satellite images and developing an understanding of them, all of us are gaining an appreciation of our connection to ecosystems both local and global.